Requirements for cloud-based BIM governance solutions to facilitate team collaboration in construction projects

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Abstract

Construction projects involve multi-disciplinary and multi-actor collaborations that generate massive amounts of data over their lifecycle. Data are often sensitive, and embody rights, ownership and intellectual property of the creator. Managing project information raises concerns about security, inconsistency and loss of data. Conventional approach of dealing with the complexities of data management involves the adoption of BIM based solutions that lack suitable means for the governance of collaboration, and access and archival of managed data. To overcome the limitations of BIM, Cloud-based governance solutions have been suggested as a way forward. However, there is a lack of understanding of construction ICT (Information and Communication Technology) practices from the perspectives of data management and governance. This paper aims to fill this gap; first, by exploring barriers related to BIM adoption and collaboration practices, in particular, issues related to data management and governance that can potentially be ameliorated with Cloud technologies, and second, by identifying key requirements for Cloud-based BIM governance solutions. A structured questionnaire was conducted among informed construction practitioners in this study. The findings reveal several barriers to BIM adoption alongside ICT and collaboration issues with an urgent need to develop a BIM governance solution underpinned by cloud technology. Further, a number of important requirements for developing BIM governance solutions have been identified.

Keywords: Building information modelling (BIM); BIM adoption barriers; BIM governance; Data governance; Construction industry; Cloud computing

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1 Introduction

The construction industry is highly fragmented and regulated, involving data intensive processes across the supply chain and lifecycle [1, 2]. During a construction project, vast amounts of data are generated that need to be coordinated and kept up-to-date and relevant throughout the whole lifecycle of the project [3-6]. On the other hand, the construction industry is under pressure to provide value for money, and promote sustainability, which have driven the industry to adopt Building Information Modeling (BIM) [7]. Despite decades of progress, the industry still faces significant challenges in adopting BIM [8, 9]. Porwal and Hewage [10] note that the rate of adoption is very low [11] due to the slow pace of change in the way the industry operates and the incompatibilities resulting from the introduction of new tools. Although team members have adopted commercial collaboration tools and practices, these vendor-specific solutions lack an industry consensus around their underpinning governance approach, i.e., the internal data structure, policies, procedures and control processes required to manage access to data at an enterprise level [12].

In recent years, collaborative governance has been developed as a new governing strategy. This strategy aims to bring multiple stakeholders together in a common platform to achieve consensus-oriented decision-making [13]. Nonetheless, several challenges associated with the development of BIM governance solutions still need to be addressed. For example, socio-organisational, legal, technical, and contractual aspects are process oriented, the understanding of which is required for effective BIM governance. There is an identified gap in research on the contextual aspects of BIM and in particular how processes can be effectively integrated with product-oriented solutions while keeping the overall system scalable and adaptable to future needs. This research is therefore aimed at establishing a robust foundation for Cloud-based BIM governance. It should be noted that Cloud technologies are chosen to assist the development of BIM governance solutions because of their high-performance capabilities (uptime), accessibility, and scalable storage capacities.

The overall aim of this study is to elicit construction practitioners' requirements for developing a cloud-based BIM governance solution for facilitating BIM adoption, and collaboration across the supply chain and lifecycle. This aim translates into the following objectives: (a) identify the socio-organizational, legal, financial, and technical barriers to BIM adoption; (b) explore current practices of Information Communication Technologies (ICT) concerning team collaboration, communication, and coordination during construction projects; (c) explore data related issues during construction projects, highlighting the role of cloud computing towards addressing data-related issues; and (d) identify the need and the requirements for developing a BIM governance solution. Conducting this exploratory, multi-disciplinary, research is important not only because it critically reviews, explores and firms up existing ICT and collaboration practices and BIM adoption barriers during construction projects but also enriches the scope and content of requirement for developing cloud-based BIM governance software solutions. Thus, it forms a rich resource of information regarding BIM governance research and development for construction practitioners, academics, and software developers.

Following this introduction, the methodology that underpins the research is presented, supported by related work highlighting BIM and team collaboration within the construction context, BIM governance, and web-based collaborative BIM solution, and Cloud computing. An in-depth description of the survey design is then given, and the most significant outcomes from the questionnaire are highlighted and discussed. Concluding remarks and plans for future work are offered at the end.

2 Background

A review of the related literature was conducted to formulate the investigation theme of this study. This includes BIM and team collaboration within the construction industry context, BIM governance, web-based collaborative solutions, and cloud computing.

2.1 BIM and team collaboration in construction

Since construction projects involve complex activities, there is a need for collaboration among team members working on these projects. Ghemawat, as cited in [14], defines collaboration as "the agreement among specialists to focus their abilities on a particular process to achieve the longer objectives of the project as a whole, as defined by a client". Collaboration involves people who work together by sharing information and processes via interacting, communicating, exchanging, coordinating and approving, hence, there is a need for team collaboration to share visions among stakeholders and to maximise the team's effort on a particular job [15].

Figure 1 illustrates data exchange between multi-disciplinary actors in a typical construction project. The magnitude of interaction is correlated with the complexity of the project and increases with geographically distributed team members. Conventional file based approaches often result in the loss of data integrity and an increase in errors. The process of data exchange is bi-directional form one actor to another thus the amount of exchanged data is big and versioning issues emerge which make it difficult to track shared data. Many collaboration solutions have been developed to facilitate construction collaboration; however, the challenges of data management and governance remain to be addressed.

Figure 1 Data exchange pathways in a conventional construction project

A logical progression to the fragmented, vendor-specific data formats was the development of neutral data exchange standards such as the Drawing eXchange Format (DXF)[1] to reduce the need for software to software (S2S) translators. The next step was the development of shared, vendor-independent data exchange formats based on the EXPRESS modelling language[2], primarily to eliminate the need for S2S translators. The adoption of EXPRESS in the construction industry led to the coinage of the term, *Building Information Modelling*, which is defined by HMGovernment [16] as "*a collaborative way of working, underpinned by the digital technologies which unlock more efficient methods of designing, creating and maintaining our assets. BIM embeds key product and asset data and a 3 dimensional computer model that can be used for effective management of information throughout a project lifecycle from earliest concept through to operation*". BIM seeks to allow stakeholder's collaboration at different stages of the building lifecycle, enabling stakeholders to insert, extract, update, or modify information during the BIM process. BIM thus emerged as a new way to manage information flow during the lifecycle of construction projects [2], offering many advantages over its predecessors [17, 18]; e.g., improved visualisation, cost estimation, project management, and most importantly, facilitating team collaboration. Even though BIM has been adopted in many cases [19], significant barriers to its adoption still remain [8, 20, 21].

Past studies [1, 3, 8, 22, 23] have investigated technical BIM adoption barriers that include *compatibility and reliability*, *fragmentation of the project team*, *resistance to change*, *lack of training*, and *issues related to the business process*. In addition, there are non-technical barriers such as *people*, *culture*, and *processes* that affect the uptake of BIM [9, 20, 22]. Legal, contractual and overall organisational implications of BIM have found to affect adoption [21, 23]. Overall consensus seems to be that the technical (i.e., BIM implementation) and socio-organisational (i.e., processes) changes should go hand in hand [24]. Most studies investigated general barriers to BIM adoption while data management issues are given a cursory treatment. For example, Porwal and Hewage [10] identified that no general agreement exist on ownership and Intellectual Propriety Rights (IPRs) of generated BIM models and artefacts, and several studies [1, 9, 22] have found a lack of clear roles and responsibilities for maintaining BIM models over the project lifecycle. Despite the efforts [25-27] in identifying BIM adoption barriers, the results are not readily usable to identify requirements for a data governance solution due to the lack of a comprehensive coverage of BIM data management aspects. This study, therefore, aims to fill the gap by identifying barriers related to data management and then translating them to a set of requirements for a Cloud based solution.

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[1] Autodesk DXF reference. http://www.autodesk.com/techpubs/autocad/dxf/reference/

[2] EXPRESS modeling language, formalized in the ISO 10303:11.

Furthermore, in a multi-actor, multi-discipline collaborative environment, trust (and the lack of) among team members and software tools can be an issue [28], which relates back to the socio-organisational and legal aspects. Despite these challenges, many organisations have actively adopted BIM in their processes, although the full potential of an integrated and collaborative BIM is still to be realised [22, 29]. However, the development and deployment of integrative and collaborative technologies in the construction industry lags behind that in other sectors because of the unique fragmented nature of the industry [30]. Successful technology implementation requires the establishment of procedures for both electronic and manual operations [15].

2.2 BIM Governance

BIM governance has not previously been investigated in construction projects in detail. Although ICT governance efforts and frameworks exist [31-34], they were not developed to meet construction industry needs and requirements [35, 36]. As for data governance frameworks, they tend to focus on data related aspects such as the overall management of the *availability*, *integrity* and *security* of the enterprise data [37]. Newman and Logan [38] define data governance as "*the collection of decision rights, processes, standards, policies and technologies required to manage, maintain and exploit information as an enterprise resource*". Whereas, according to Rezgui, Beach [9], BIM governance is "*the process of establishing a project information management policy across lifecycle and supply chain underpinned by a building information model taking into account stakeholders' rights and responsibility for project's data and information*". Conventional standalone data governance frameworks are, therefore, not wholly applicable to the construction industry, without the consideration of social, organisational and legal aspects.

It is important to differentiate between *governance* and *management*. Governance is about determining who enters and makes decisions and how, whereas, management is the process of implementing these decisions [39]. Overall, almost all organisations face an increasing challenge regarding information governance that can be met by an effective governance approach supported by standards [40].

There is a lack of overall governance within current construction projects; therefore, there is a general consensus on the need to develop a generic data governance solution to facilitate BIM adoption in a collaborative built-in environment across disciplines and supply chains during the building lifecycle [12]. From a data governance standpoint, there are several requirements [1, 9, 29, 41] for overcoming BIM adoption and team collaboration limitations, namely: (a) protocol development, (b) establishment of responsibilities among disciplines, (c) sharing via a common model that can be stored centrally or hosted on distributed environments, and (d) improved communication among disciplines. Also, to raise awareness, intensive training should be introduced, along with the definition of formal responsibilities among stakeholders, across disciplines and at different stages of the lifecycle. However, to effectively develop a BIM governance solution, there is a need to take into account several aspects, including: BIM data, project's lifecycle, supply-chain complexity, BIM, team members' rights and responsibilities, underpinning technology, and policies & standards [36].

2.3 Web-based collaborative BIM solutions

Use of web-based technologies has gradually become a common practice in construction project management to achieve the integration of contractual, organisational and information aspects [15]. It is a challenging task to encourage collaboration among geographically distributed teams, with different practitioners representing different organisations, working on typical large construction projects [15]. Use of collaboration technologies creates a shift towards virtual organisations in which users are not strictly required to occupy a particular workspace next to each other, and which, therefore, provide the flexibility to work from any physical location. Also, integration of communication with computing technology makes it possible to communicate richer and more complex information [15].

Further, there has been a development in commercial BIM servers, which can solve some of the team's collaboration issues, and limitations. For example, available commercial BIM servers include the Onuma system, Revit Server, ProjectWise, Graphisoft BIM Server, EDMmodelServer and, more recently, Autodesk BIM 360 Glue. Also, there is an open-source BIM server. However, these BIM servers are inclined to use proprietary management data structures, and these systems use either central or local servers for data management and storage [9]. Following table shows widely used collaborative solutions for BIM.

Table 1 Widely used collaborative solutions for BIM

Technical requirements for developing collaborative BIM servers are identified by Singh, Gu [29], including: a central model repository linked to other federated data repositories; a variety of spaces for public and private models; Global Unique Identifier (GUID) for object identification; Information Delivery Manuals (IDM)-based specifications; secure access to the model; hierarchical structure of the model, based on user's requirements; checking that models are securely uploaded, downloaded and transferred; user interface customisation; real-time operations via the web (viewing and printing); ease of checking properties of objects; and different levels of detailed objects and sub-models. Nevertheless, these requirements fall into one category i.e., technical requirements, whereas, this study looks for other categories (e.g., legal and socio-organisational requirements).

2.4 Cloud Computing

Due to recent development in distributed environments technologies, e.g., cloud computing, it becomes increasingly important to utilise these technologies in developing BIM collaboration tools. Mell and Grance [42] define cloud computing as "a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction".

Most of construction organisations host their collaborative solutions on their local servers. This leads to many issues such as limitation of remote access to the hosted BIM data, and difficulties in upgrading infrastructure when hard drives reach capacity because of the massive size of BIM [36]. Although many researchers demonstrate the numerous advantages of using cloud computing technology in managing and storing BIM data such as accessibility, storage scalability, and high-performance computing capabilities [43], the process dimension of a construction project is not taken into full consirdation [9]. Furthermore, recent cloud-based solutions tend to be proprietary, with access to data depending on the company that provides the service [12].

The challenge in this study is not only to address technical or non-technical requirements but also to integrate the two for future development of BIM governance solution. However, in order to gain the maximum benefits of BIM technology and to overcome BIM adoption barriers in the construction industry, it is necessary to: (a) address a variety of organisational, procedural, legal, and technical issues [10]; (b) carefully study BIM collaboration-related aspects together with the current situation of BIM adoption process in the construction industry [20]; and (c) develop a governance solution for facilitating collaboration during the building lifecycle [9, 44].

Even though BIM offers an effective means of dealing with the complexity of data generated by team members during a construction project, there is still some issues occurs such as data inconsistency, data versions, and data loss. According to Rezgui, Beach [9], from an ICT point of view, development of a governance solution for BIM collaboration among multi-disciplines and multi-actors across a building lifecycle, with its underpinning cloud storage infrastructure, would tackle most of these data-related issues during BIM adoption within construction projects.

3 Methodology

The collaboration process of construction teams differ from other disciplines [45]. There is a lack of studies that investigate collaboration practices, data management, and governance issues from a socio-technical perspective. This forms the gap addressed by the present paper to fully capture requirements for BIM governance using an appropriate scientific approach, i.e., questionnaire and formal interviews. Therefore, the main aim of this research paper is to investigate the need for a BIM governance solution as well as identifying its requirements. This is done by exploring (a) the current situation of BIM adoption, (b) ICT and collaboration practices, and (c) data management practices in construction projects. Consequently, this study is underpinned by the following research questions: Q1. What are the current barriers to adoption of BIM? Q2. What are the current ICT and collaboration practices of construction teams during construction projects? Q3 What data problems occur during construction projects and what is the potential role of Cloud technologies towards addressing them? Q4. What are construction practitioners' requirements for developing BIM governance solutions?.

3.1 Consultation questionnaire

This study is considered exploratory research. Thus, a questionnaire was chosen as an appropriate research instrument [46]. The questionnaire design was based on methods discussed in [47, 48]. The stages followed were: identifying the questions to be answered; generating questions; testing and altering the questions as necessary; distributing the questionnaire; collecting responses and analyzing data. The design of the questionnaire is informed by a thorough review of the literature on BIM, its adoption and ICT and team collaboration practices during construction projects. Therefore, the outcomes of the literature review formed the basis of all questions asked in the questionnaire. Therefore, the questionnaire design is divided into five sections: (a) Demographic information about respondents and their organisations; (b) BIM adoption barriers with respect to socio-organisational, legal, technical and financial factors; (c) Practitioners' collaboration and ICT practices on typical UK construction projects; (d) Data implications and issues during construction projects data and the role of cloud towards addressing them; and (e) Practitioners' opinions and requirement with regards to a BIM governance solution development. Moreover, the questionnaire' questions are open-ended to enable the respondents to not only select an answer from pre-offered options but also to add further information using a comment box provided at the end of each question. Further, some questions have a different ranking. For example, Ranking for the question regarding "Used communication tools between the team's members" is (1: Never; 2: Rarely; 3: Sometimes; 4: Often; 5: Always.). Questions of this type are presented in table fromat with a footnote at the end of each table describing the ranking of the question.

To ensure the quality and the integrity of the questionnaire, a pilot study was distributed among colleagues within the same area of interests. Their feedbacks were incorporated into the final questionnaire. Also, non-probability sampling was the technique used for reaching targeted participants, supported by follow-up calls to improve the response rate. It is known that it is better to have a high number of responses to such questionnaires to obtain robust results. While there are no closely defined rules for sample size [49], sampling in maixed method research usually relies on small numbers, with the aim of studying the responses in detail [49, 50]. Nonetheless, it is also true that an appropriate sample size for a in maixed method study is the one that adequately answers the research question [51]. Thus, it is argued by the authors that the quality of the chosen panel is more important than the size of the chosen panel. AEC professional have been chosen according to a number of criteria including sufficient practical experience of BIM; adequate knowledge of data management; and willingness to participate.

With the assistance of key experts in this field as well as the professional network [52], the panel of respondents was assembled. The total number of the expert panel was 200 AEC professionals. For small-scale research projects, a general principle is to have a final sample of at least 30 respondent [48]. Survey Monkey was used to design and distribute the questionnaire [53]. The total number of BIM professionals who opened the questionnaire is 118. Overall, 97 positive responses were received, a response rate of 48.5%. Also, participation in the survey was voluntary, and answers provided were kept confidential, used for only for statistical purposes, and released in aggregate form only.

Table 2 respondents' demographic information

3.2 Complementary semi-structured interviews

Twenty-three questions were initially designed to obtain more detailed information regarding BIM experts' perception of current ICT and collaboration practices within the construction industry. These questions evolved from the literature review and initial questionnaire findings. In order to ensure that the questions were directed, simple and specific while avoiding double-barreled questions, a pilot study involved several senior academics at Cardiff University with a view to provide feedback for improvement.

Interview participants were selected from the questionnaire respondents. There was a section in the questionnaire on whether the respondents would be interested in participating in a further interview. Eighteen BIM experts agreed to participate in the semi-structured interviews. The interview questions focused on obtaining more details with regards to BIM adoption barriers, current ICT and collaboration practices, the role of collaborative BIM standards, and BIM experts' requirements for developing a cloud-based BIM governance solution. Interview results were used to glean further insights and corroborate key findings from the questionnaire. The interviewees were informed beforehand that the interviews would be recorded, and the confidentiality of the information would be maintained.

4 Findings and discussion

This section highlights outcomes from the consultation (through a questionnaire) and then discusses these findings to diagnose the current situation of collaboration and ICT practices during construction projects.

4.1 Respondents' characteristics

Practitioners in the construction industry in the UK were the main contributors to the resulting questionnaire. Demographic and work related characteristics of the respondents are given in Table 1. Among 118 respondents, 107 (93.04%) were male and (8%) were female. At the time of the questionnaire, the majority of respondents have been working in the construction industry for more than 20 years (29.57%). The majority of respondents have graduated from college and had higher qualifications (72.5%). Nearly (58.5 %) of respondents works in companies aged more than 30 years while others work in companies aged less than 30 years. At least (1.1%) of each discipline has participated in this study. However, BIM managers and architects are the heavy contributors with (33.7%) and (32%) respectively.

The following findings will be presented in four areas, including (a) BIM adoption barriers, (b) collaboration and ICT practices during construction projects, (c) data management issues and the role of cloud computing, and (d) the BIM governance solution requirements.

4.2 BIM adoption barriers

There are several barriers to BIM adoption in the UK construction industry, consisting of socio-organisational, legal, financial and technical aspects. Exploring these barriers is an essential step towards the development of a BIM governance solution. Therefore, this section sheds light on the major BIM adoption barriers.

4.2.1 Socio-organisational barriers

Addressing socio-organisational barriers is crucial for the development of a BIM governance solution. Hence, Figure 2 presents these barriers to BIM adoption in the UK construction industry. It shows that the most significant barrier is team resistance to change (70%), and then generational gaps in BIM skills and understanding between junior and senior respondents (63.6%), followed by the barrier to collaboration, e.g., trust within a team, and the barrier to adopting a single management process for multiple disciplines, across the lifecycle and supply chain by (54.5%) and (45.5%) respectively. However, the barrier of organisational cultural, values and beliefs that are shared within an organisation (42%) is higher than the barrier of the team structure and relationship of the team project

(39.8%). The final barrier, at the lowest level, is undefined roles and responsibilities of team members (43.1%).

The updated BIM socio-organisational barriers include such significant aspects as team resistance to change, leading to generational gaps in BIM skills and understanding between junior and senior practitioners. This breakdown shows that team members know their roles and responsibilities but are resistant to change. It is also important to note that working with teams of a different culture and different traditions, in which responsibilities and roles are also unclear, leads to collaboration issues e.g., trust [28, 54]. These collaboration issues might produce difficulties in dealing with the generated data. Overall, key respondents have stated that various people/groups are trying to define too many things related to BIM; those things are not yet well defined, incorporating only "guidance" but not legislation. This, in turn, has created a reluctance to work toward an undefined goal.

Figure 2 Socio-organisational barriers to BIM adoption

4.2.2 Legal barriers

Six potential legal barriers have been identified that may hinder BIM adoption. Figure 3 shows that lack of defined liability for wrong or incomplete information input is the greatest barrier (65.4%), followed by the second barrier, which is a lack of intellectual proprietary rights and fair practice standards for electronic information and documentation (53.1%). The lack of clear regulations related to practitioners' roles, responsibilities, and authority, is the third strongest barrier (45.7%). The fourth strongest legal barrier is presented by the lack of collaboration standards (44.4%). The fifth greatest barrier is the lack of personal indemnity insurance coverage and maintenance, due to unknown liabilities associated with shared projects. The final and the least significant legal barrier consists of historic government regulations that do not meet the industry's current and future needs.

Legal barriers have been another major concern when work is accomplished in a collaborative environment [55, 56]. When adopting BIM in collaborative projects, many collaboration issues related to legal concerns such as IPRs, or the ownership of the model can appear. As one of the respondents commented, "Ownership to answer the question of who takes responsibility for what is done in the model". The results of the survey strongly confirm the legal barriers to BIM adoption mentioned in the literature. However, this research strongly emphasises that lack of defined liability for wrong or incomplete information input be the major barrier. The reason is that there is no clear regulation related to participant roles, responsibilities, and authority, to intellectual proprietary rights, or to fair practice for electronic information and documentation.

In addition, there is a need to develop government regulations because the existing ones do not meet the current and future needs of the industry. In fact, the government is moving towards developing its regulations so as to meet current developments in the construction industry. As one practitioner stated, "Standards are now catching up e.g., PAS 1192-2:2013". However, another practitioner added, "Standards progressing, but everything else is moving too slowly. Technologies leading push but the focus is in the wrong areas; i.e., software developers should not be the determinant for BIM". This strongly highlights the role of the UK government in the development of BIM regulations, standards, and legislation. Moreover, working on shared projects increases the risk of unknown liabilities, which makes it difficult for insurance companies to cover and maintain Personal Indemnity Insurance (PPI) without increasing the cost.

Figure 3 Legal barriers to BIM adoption

4.2.3 Financial barriers to BIM adoption

It is clear from Figure 4 that the training cost is the main financial barrier to BIM adoption by (68.2%), followed by the cost of initial software setup by (68.1%). Tight budget and existing small profits margins on projects became thirdly by (64.7%). More than half of the respondents agreed that the cost of initial hardware setup is a very common financial barrier. Interestingly, the increment of PII due to shared liability policies is less of a barrier than software maintenance and update costs.

Figure 4 Financial barriers to BIM adoption

However, these financial barriers have more effect on small organisations than large organisations. Many respondents agreed that the major financial barrier is the cost of the initial software setup, followed by the cost of initial hardware and software, together with maintenance and updates. Because BIM represents new technology, training in its use is required, and many respondents point out that training costs are very high, especially for contractors and FM teams. The use of BIM might face budgetary limits and small profit margins on construction projects. In that respect, one practitioner revealed that BIM is cost effective compared to traditional methods, but another argued that SMEs struggle to see its benefits due to the factors mentioned above, especially the cost of software, in addition to the uncertainty of obtaining constant work. Therefore, the efficiency of BIM usage is limited. However, one practitioner argued that, because UK industry focuses on cost rather than on added value from investment, the current business models do not support collaboration. Overall, there is a general increase in time and cost implications, as the increase in coordination leads to increased information and associated teething problems.

4.2.4 Technical barriers to BIM adoption

Identifying technical barriers to BIM adoption is an important to the development of a BIM governance solution. Figure 5 shows technical barriers to BIM adoption in the UK construction industry. It demonstrates that lack of technical training is the highest barrier (69%). The second greatest technical barrier is a lack of compatibility between various standards-based e.g., IFC products across the lifecycle and supply chains (59.8%). The same percentage (55.2%) are found for the lack of compatibility in software and lack of data integration between stakeholders during the lifecycle. Surprisingly, the results show that, as agreed by a third of respondents, lack of support for data integrity, user authentication, data security and access control is the fourth technical barrier to BIM adoption. Also, almost quarter of respondents (23%) agreed that the barrier of privacy constraints associated with externally sourced virtualised storage e.g., cloud, and the barrier of lack of compatibility between existing and new hardware, occupied the same level of significance.

Figure 5 Technical barriers to BIM adoption

Barriers related to technical factors are another major concern in BIM adoption. Lack of compatibility between existing and new software is considered the highest technical barrier, as compared with the barrier of lack of compatibility between existing and new hardware. Although there are software packages that support the export/import of open standards, e.g., IFC, the findings indicate that there is a lack of compatibility between various standards-based e.g., IFC products. As one practitioner stated, "*Currently the software is designed one-way translation, thus BIM will not work on any current design software*". Another practitioner supported his colleague, commenting, "*Software developer vested interests in their proprietary software is a big blocker to open BIM and collaboration*".

There is general agreement on the lack of technical training among construction practitioners. A further major technical barrier to BIM adoption is the lack of support for data integrity, user authentication, data security and access control as well as for privacy constraints associated with externally sourced virtualised storage (e.g., cloud), leading to a lack of data integration among stakeholders across the lifecycle and supply chains. Once these technical barriers are tackled, adopting BIM effectively would be achievable.

To sum up, several barriers need to be addressed when adopting BIM as a new collaborative approach. While recent research in BIM development has investigated barriers to BIM adoption [1, 7, 22], the present study has focused on a potential solution consisting of a governance solution supported by a sustainable data storage infrastructure. There is a general lack of understanding of BIM, especially among client bodies, as well as a lack of the skills required to adopt BIM. Moreover, there are contractual issues that might hinder the adoption of BIM in the UK construction industry. As one practitioner stated, "*Contractual relationships and adversarial forms of contract are more important than technologies*". However, another practitioner argued that the barriers cited are problems already present and in effect without BIM, and thus do not provide adequate reasons for rejecting it. This view is supported by the practitioner who observed: "*All above issues are obstacles, but some of them are* *rather perceptions than reality and based on people's unwillingness to find out what really exist. On a global level e.g., in Nordic countries, most of the issues have been resolved*". Moreover, [9] maintained that developing and implementing the BIM governance solution would successfully overcome such barriers.

4.3 Collaboration and ICT practice in a typical construction project

As construction projects involve multi-discipline, multi-actor collaboration during the project lifecycle, results from the survey also explored the current ICT and collaboration practices among the team on typical construction industry projects. This section demonstrates these practices on a typical construction project.

4.3.1 Responsibility for maintaining collaborative environment

Setting up, maintaining a team collaboration environment is a very important task on collaborative construction projects. Figure 6 shows that most respondents agreed that project managers are responsible for preparing the construction project's collaborative environment (46%). However, nearly same percentage (45%) agreed that the responsibility of this is varies from one project to another. Only a small percentage agreed that setting up the project environment is an IT manager's responsibility. With the adoption of BIM in construction projects, the need for a dedicated BIM manager becomes crucial, as the majority of construction respondents agreed by (80%).

Figure 6 Responsibility of maintaining a project's collaborative environment

4.3.2 Used software for project management & planning

Management and planning software are critical tools for planning and managing construction projects. Figure 7 shows that the majority of respondents are using Autodesk Navisworks for managing their construction projects (71.3%). Followed by Microsoft packages (MS Word, MS Excel) by (55%). However, the use of Primavira and Solibiri is almost the same. Small percentages (2.5%) of respondents only use Sage Masterbuilder. The high percentage of using Navisworks compared to others is due to its up-to-date functions that support BIM implementation and review.

Figure 7 Used software for project management & planning

4.3.3 Used models for design & construction process

Most construction companies adopt a process models to facilitate work on the project. However, due to the UK governments' aim of using BIM as a fully collaborative delivery system, many organisations such as Royal Institute of British Architects (RIBA) and Construction Industry Council (CIC) are working towards this goal by improving their models of work plans. Figure 8 shows the used lifecycle on typical UK construction projects. It demonstrates that the RIBA plans of work with its different versions (Outline Plan of Work [57], BIM Overlay [58], and Plan of Work 2013 [59]) are used more than the use of CIC [60]. In addition, the figure illustrates that, some construction companies are still using RIBA Plan of Work 2007, there is a rapid adoption of newly released project lifecycles, such as RIBA's Plan of Work 2013.

Figure 8 Used model for design & construction process

4.3.4 Procurement methods

With the rapid development of the construction industry, new procurement methods in construction projects have emerged, such as prime contracting, framework agreement, etc. Table 3 illustrates the procurement methods more likely to be used during construction projects. It shows that the design and build is the most commonly used procurement method, followed by the traditional method. The Framework agreements procurement method was the third most commonly used method, along with the two-stage tendering method. However, the private finance initiative and prime contracting methods are rarely used. This indicates that the current construction industry still heavily relying on old procurements methods that do not fully support BIM collaborative approach. Thus, procurement methods should be developed or updated to include the collaborative side of BIM.

Table 3 Used procurement methods

4.3.5 BIM collaboration solutions usage

When construction team members collaborate with each other on the same BIM model many issues arise, due to the usage of different software and tools. This has led to the development of collaboration solutions that aim to bring a construction team together. Figure 9 illustrates the level of the selected respondents' usage of BIM servers to facilitate team collaboration. It shows that the use of commercial BIM collaboration servers is at a higher level than the use of open-source BIM collaboration servers among the selected respondents. RevitServer is the leading collaboration tool (33%), followed by Autodesk Buzzsaw (31.9%) and Bentley ProjectWise (27.8%), whereas the level of Bentley AssetWise usage is very low (2.8%). Interestingly, the level of Onuma systems "BIM Storm" usage is (0%). The level of use of open-source BIM servers such as BIMServer and EDMmodelServer is also very low, only (2.86%) and (0%) of the selected respondents having used or experienced it. The majority of the selected respondents (34.7%) who did not use any of the above-mentioned collaboration solutions are using other collaborative solutions such as BimXtra[3], UNIT4 Business Collaborator[4], Asite[5], or 4Projects[6].

Figure 9 The level of using BIM collaboration servers

4.3.6 Communication technologies/tools

Communication between construction project team members is important for effectively and efficiently completing construction project tasks. Table 4 shows the communication tools/software used for facilitating collaboration across the team. It demonstrates that emails are the communication tool used most often, followed by face-to-face meetings. Next most popular are mobile phones and landlines, in that order. According to the same table, the use of teleconferencing and online meeting tools is low compared to that of earlier technologies and tools; there is rare use of online meeting tools. The separation between communication tools and collaboration solutions bring many issues to the team during the construction project such as loss of important data with regards to made decision during the communication process.

Table 4 Used communication tools between team members

4.3.7 Data storing methods

Construction data must be stored in a suitable place for archiving and reuse purposes. Table 5 shows the methods currently used by construction respondents for storing and archiving their data. It shows that the most favored method is the network drive hosted by the practitioner's company. The use of paper is the second most commonly used method of storing data. The levels of use of flash storage and cloud solutions are almost the same. However, the level of using personal PCs/laptops to store data is higher than the use of optical media. Finally, the use of a portable external hard drive is less popular among respondents. The use of company hosted hard drive raises many issues and concerns to the majority of practitioners such as the limited space of storage, access rights to data is restricted and limited by company IT department. Therefore, they maintain a printed copy on paper for their data to preserve them from loss. Significantly, the use of cloud storage solution is more popular than other traditional storage methods.

Table 5 Respondents' methods for storing their data

4.3.8 Project's data sharing & exchanging methods

[3] CLEARBOX. BIMXtra. Reference: http://clearboxbim.com/products/bimxtra
[4] UNIT4. Reference: http://www.unit4.com/uki/about/partners/business-collaborator
[5] ASITE. Asite cBIM Manager. Reference: http://www.asite.com/index.php/applications/category/application-cbim-manager/
[6] 4PROJECTS. 2015. 4BIM [Online]. Available: http://www.4projects.com/OurProduct/4BIM.aspx

Sharing and exchanging data with other team members during the project lifecycle is essential on any typical construction project. Table 6 shows current methods of sharing and exchanging data among the project team. It shows that there is a strong dependency on using email for sharing/exchanging project's data, followed by use of a shared storage drive hosted over a company network. It also reveals considerable reliance on paper for sharing and exchanging data. However, there is little use of external hard drives for sharing/exchanging project's data. Surprisingly, the use of cloud storage solutions such as Dropbox [61] for this purpose is greater than the use of paper, optical media and flash storage devices. The use of emails is a bad practice for sharing/exchanging the project's data because its create many issues such as different versions, data inconsistency, etc. This finding makes it clear that the use of cloud storage solutions has become popular for sharing and exchanging construction project data.

Table 6 Practitioners' methods for sharing & exchanging

4.3.9 Common data formats used during a project

Although sharing and exchanging project data is important, it is also essential to know what the typical data formats are that are being shared/exchanged. Table 7 shows different types of the data format used during a typical construction project. It shows that there is a strong reliance on the Portable Document Format (PDF) file format. It also demonstrates that Microsoft packages data formats are used more frequently, specifically Word and Excel file formats. Also, the figure shows that the Autodesk file format is used more than the Autocad file format for generating design data. Remarkably, the use of various image formats is very high. Working with diverse data formats during a construction project presents both compatibility and governance risks: regarding, for example, IP, ownership, access rights, data inconsistency and liability. Moreover, the use of un-editable data formats such as PDFs makes it difficult to track changes that have been made to the data file. Thus, makes the possibility of losing the track of changes that occurs to a specific data.

As for ICT and collaboration practices during a construction project, the findings of this study shows that the majority of respondents agreed on the need to introduce new roles when adopting collaborative BIM approach such as BIM manager. Due to the strong collaborative relationship among team members during work on construction projects, many collaboration issues arise such as data errors and inconsistency that lead to legal disputes. This indicates that a successful collaboration strategy must take account of the actors' collaboration concerns such as access rights, ownership, IPRs. Some communication tools are used in construction projects, which should raise the concerns of not effectively recording made decisions. This study shows that there is a strong reliance on email for communication, even where the company has its own BIM server solutions for communication and collaboration. Although respondents use ICT technologies for communication, face-to-face meetings always take place during the project. In collaborative projects on which multiple actors within multi-disciplines work together, various methods are used for sharing/exchanging project's data. The results from the survey, again, show a strong reliance on emails for sharing and exchanging construction projects' data with other team members. Some construction respondents use the following tools for sharing and exchanging data: Business Collaborator (BC) and Project Extranets such as UNIT4, EDMS such as Buzzsaw, Asite, etc. However, even with the existence of these collaborative solutions, construction practitioners still use emails for sharing/exchanging their data.

During the construction project, the team produce and work with different file formats; thus the construction industry faces the challenge of adopting a single file format with the ability to host all the data generated during the project. Collaboration through the use of these different file formats by different actors leads to an increase in IPRs, ownership, and data responsibility concerns. Practitioners use software of various design in their organisations when producing building designs. Although some respondents use popular design software such as Autodesk packages, Bentley packages, etc., others use alternative software solutions, including BIMXtra, RhinoBIM, and Tekla products. One of the respondents stated, "*I have 25 years' experience in BIM software. In principle, AutoCAD provides dumb data. Revit provides information. Bentley provides similar. But none of the above are true BIM*". In order to successfully manage their data and files, many organisations adopt shared place technology to accommodate all their files and data from different sources. For that reason, commercial BIM collaboration solutions have been used more often than open-source BIM collaboration solutions.

The use of various traditional procurements, design & construction process, communication tools, storage methods, sharing/exchanging methods, different file formats leads to many issues during the collaboration process during the project. Hence, developing a governance solution with the ability to control and manage these different, and possibly unrelated, file formats can be very beneficial.

Table 7 Most commonly used file format when sharing/exchanging data

4.4 Data related issues and the role of cloud computing

This section of the findings (a) shows the impacts of insufficient data management solutions; (b) highlights most common issues related to the data generated during construction projects; and (c) explores the role of cloud computing in addressing them.

4.4.1 Impact of insufficient data management solutions

The use of insufficient data management solutions may affect the construction project as shown by the results presented in the following figure. Figure 10 demonstrates that data errors and inconsistency are the main results of using insufficient data management solutions during construction projects (82.8%), in addition to other negative impacts such as project delays (74.7%), and poor documentation (67.8%), and negative effects on costs (64.4%). These raise the point of even tough that there are data management solutions as there is a need for a more accurate solution such as data governance to be incorporated into the existing data management solutions. During a construction project, massive amounts of data are generated. Besides the lack of interoperability between systems, with several standards competing to manage data [30], the use of inadequate data management software raises many data-related issues during construction projects. These issues include data inconsistency, resulting in poor documents that lead to project delay. One practitioner noted that this problem might also lead to "*legal disputes*". Data inconsistency issues, e.g., different versions, and data loss, are the main concerns for the respondents. These issues are likely to arise when people are working within a collaborative environment, which in turn affect decision-making. Accessing data files is another major issue, Shen, Hao [30] pointed to the difficulty of accessing accurate data, information and knowledge at the right time at each stage of the construction project lifecycle. Moreover, it can be clearly seen that data liability-related issues, such as the security, confidentiality, and privacy of data files, are of greater concern than before to the respondents, due to the nature of the BIM collaborative working environment.

Figure 10 Impact of insufficient data management solutions

4.4.2 Common data issues within construction projects

Many issues regarding generated data rise during the project lifecycle. Figure 11 shows the most common issues occurs during the project lifecycle. It demonstrates that data inconsistency, e.g., different versions or loss of data, is the most prominent data-related issue arising during work in the construction industry (81.2%). The second most common issue is data compatibility when data are shared/exchanged among respondents (54.1%). Another major issue is the big size of data when sharing and storing documents (51.8%). Access to data files of this size is a further issue, as nearly third the respondents agreed (34.1%). However, data security, confidentiality, and privacy as well as data liability-related concerns are considered less important than previously mentioned issues. Nonetheless, data privacy is a big issue as reported by a BIM practitioner "*No privacy, all work within a BIM/Revit model becomes public - issues with companies copying our hard work*".

Figure 11 Most common data issues within construction projects

Although some companies use different asset management solution, there is a problem with data accuracy as reported by a BIM practitioner "The accuracy of existing data, we have five different asset management systems". One practitioner strongly emphasised the need for data filtering, due to the massive amount of generated data. Another respondent added that one big problem is a lack of focus on levels of detail and fit-for-purpose information. However, infrastructure is the key when working globally; in other words, it is necessary to enforce and track data from one practitioner to another to make sure that everyone is working on the correct data at a given time. One respondent argued that "*All the above issues are traditional problems in construction projects; i.e., they have nothing to do with BIM except that there are many success stories where BIM has removed or radically reduced the data management problems*". This observation suggests that nearly the majority of previously mentioned issues have been partly solved via the use of BIM in the construction industry. Thus, having a governance solution to support BIM implementation during construction projects would also help to reduce these issues.

4.4.3 Cloud technologies in facilitating collaborative BIM

Using Cloud technology in developing BIM governance platform might solve many problems related to the vast amount of generated data. As shown in figure 12, the majority of respondents agreed that the use of cloud computing would facilitate access to data files (83.3%). Another problem that might be solved by the use of BIM governance solution development with the support of cloud computing is data inconsistency e.g., different versions and data loss, due to putting all data in one place. Also, the use of cloud computing plays an important role in solving issues of data file size when sharing and exchanging data files as nearly half respondents agreed (53%). There was less agreement by respondents that the use of cloud computing might solve issues related to data liability, security, privacy, and confidentiality. However, nearly third the respondents agreed that the use of cloud computing would solve problems related to data compatibility.

Figure 12 Role of cloud towards solving construction data-related issues

One BIM expert suggested that cloud computing may or may not solve existing problems, while the majority agreed that it may help with access to data files and data file sizes, with the processing of large amounts of data and information, or with analysis, thus reducing the cost of high-powered hardware. However, one of the respondents observed that access to data files depends on project management by teams along with infrastructural support (i.e., the availability of internet connection, etc.) and that only certain "cloud" software solutions, pertaining to BIM, can act as common-format aggregators. "Cloud computing" plays no part in liability until it is factored in as one. Moreover, nothing will prevent "data inconsistency" within a cloud-based EDMS if there is no protocol to govern it. There are also issues related to security with cloud-based systems a case in point hacking attacks. As for liability, it depends on the correct and relevant content, in which cloud plays no role. Also, compatibility is related to the file format and standards, which, again, are not related to the Cloud unless the BIM tool that produces and handles data is totally re-engineered. File size problems relate to the bandwidth, and a purely cloud-based solution can, in fact, make these problems much worse; for example, large files require replication to local copies until much greater and more reliable bandwidth is available. There is also strong evidence that development of a governance solution with its cloud infrastructure will facilitate ongoing collaboration and ICT practice during construction projects [12].

4.5 BIM governance solution requirements

The following subsections will discuss in depth the critical factors that can influence the overall development of a robust BIM governance solution. As this section highlights the findings of the questionnaire, with a focus on the need to develop a BIM governance solution as well as the requirements for developing such solution.

4.5.1 Respondents opinions regarding BIM governance solution

One of the aims of this study is to investigate the need for a governance solution for facilitating BIM collaboration across the lifecycle and supply chain. Therefore, the finding from this study shows that there are many issues rise during team members' collaboration, which emphasise the need to develop a BIM governance solution to tackle most of these issues. Table 8 shows opinions are used to determine the future implications of BIM usage for the construction industry and the level of agreement on developing a BIM governance solution. The majority of respondents agreed that the new BIM management solutions will change the way teams collaborates during a construction project. Also, they agreed that BIM will improve project quality and efficiency in the construction industry. They also agreed that BIM will speed up the supply-chain collaboration during the project's lifecycle.

However, the majority agreed that developing a BIM data governance solution would tackle most existing BIM collaboration problems. One practitioner added the following comment: "*The BIM collaboration problems are very complicated. There is no single solution for those, but a good data governance solution can improve the situation*". This statement emphasised the need to tackle issues related to team collaboration by designing a good BIM governance solution. Another argued that there could not be a common model, because BIM is consistent and must incorporate several domain models with clear ownership, due to the varying responsibilities and data needs to be dealt with. However, there is an issue related to the way these models are facilitated/federated/linked together. A well-structured model server would be a good solution on the conceptual level of the model, but not on the level of an integrated model consisting of several sub-models.

Table 8 Practitioners' opinions about BIM data governance solution development

4.5.2 Practitioners' requirements for developing a BIM governance solution

The findings from the questionnaire show that addressing socio-organisational and legal requirements is more important than addressing technical requirements when developing a BIM governance solution. Table 9 summaries practitioners' requirements ordered according to the intensity of importance. It shows strong agreement on the first requirement category, namely, socio-organisational and legal requirements for developing a BIM governance solution. This category includes: improving communication among disciplines, developing collaboration protocols, defining clear roles and responsibilities for stakeholders across disciplines through the lifecycle, awareness raising, help, and support, standardizing overall data management policy, and provide intensive training.

Table 9 BIM governance solution requirements

The same table shows that the level of agreement on the second category, namely, technical requirements, is lower than the level of agreement on the category of socio-organisational requirements. This second category includes: providing a notification system to inform other participants of changes being made on the model, providing a real-time mechanism with which team members can share/exchange information, establishing a central repository for storing data online, viewing and printing models online via the web, providing security checks when uploading, downloading and transferring models, providing a secured log-in with access rights, and allow users to customise their interface.

Since the design of this question allows the respondents to add new requirements, they mentioned new other requirements, including: facilitating/federating/linking different BIM models together, and taking account of BIM sub-models. One stated that it is crucial to work with live data rather than dumb data because the current systems for planning work do not understand BIM environment. Also, it is important for data owners to be able to decide when to publish their data. Other important new requirements include the ability to coordinate at the same time as modeling, the ability to add additional dimensions to a modeling package, and the ability to incorporate more work in a design stage process that has not yet accommodated this change. Other respondents argue that real-time sharing is not needed because disclosure of on-going work only confuses other team members and can lead to a wasted effort if changes are made on the basis of incomplete data. Table 9 provides a simplified snapshot onto key overarching themes that emerged from the consultation. These have been grouped into technical and non-technical (i.e. socio-organizational and legal aspects). Furthermore, the system developers should take into account the simplicity of governance solution so that training material are available online and presented in easy to follow instructions. Nonetheless, the solution should be cost effective and affordable by majority of construction companies, including Small-Medium-Enterprises (SME).

Moreover, practical evidence [12] suggests that utilizing the BIM governance solution with the support of cloud computing for data processing and storage capabilities will positively minimise BIM collaboration issues. The development of BIM governance solution still requires further research, as can be seen by considering the various BIM adoption barriers, current ICT practices, and BIM governance requirements. The authors, however, argue that developing a BIM governance solution with its cloud computing infrastructure will play a crucial role in addressing the above BIM adoption barriers and ICT & collaboration issues.

4.6 Proposed Cloud-based BIM governance solution

Outcomes from respondents corroborate the need for a technology solution underpinned by a legal framework to govern collaborative processes during BIM-based projects. Hence, BIM experts' requirements are translated into a BIM governance implementation framework. Figure 13 illustrates the proposed Cloud-based BIM governance solution. Governing collaboration processes of team members should be orchestrated by a governance platform integrated within a Cloud Service Provider (CSP). The platform is controlled by a "BIM governor" who has full control over the governance platform's functionality. During the project lifecycle, team members have limited access rights to the shared data granted to them by the BIM governor. This will ensure that all shared data are controlled, monitored, and tracked thus eliminating some of the collaboration issues identified earlier in the result section. Moreover, the platform's functions should address the requirements of BIM practitioners. Due to uniqueness of each construction project, each stakeholder has a set of roles given to him/her at the beginning of the project which make it difficult to produce a set of requirement for each stakeholder. Thus, the acquired requirements are high-level requirements and reflect the requirements of the main actors within a construction project. For example, (a) the platform should have a notification system, and (b) it should provide real-time sharing process, etc. One important aspect is that the platform should be developed based on paper-based collaboration standards, so that the complexity of these standards is concealed behind a user-friendly graphical interface. Nonetheless, due to massive shared data files and need for high-performance capabilities when analyzing some of BIM files e.g., environmental calculations, Cloud hosting would be the ideal location to integrate such a solution. The technical development of such a platform will take place in the next following stages of BIM governance research and development.

Figure 13 Proposed Cloud-based BIM governance solution

5 Conclusion

There is a growing trend towards the adoption of BIM in the construction industry, because of its significant role in addressing several issues related to collaboration during construction projects, in addition to increasing stringent regulatory enforcements [16]. However, this adoption of BIM requires the construction team to accept new collaborative methods. This study seeks to explore issues, practices during team collaboration and thus identify BIM governance solution requirements.

Informed practitioners form key contributors to the resulting investigation, which used a questionnaire as its main research instrument.

The key findings reveal that construction industry still faces many issues and barriers with respect to socio-organisational e.g. ‘people resistant to change’, legal e.g. ‘lack of defined liability for wrong or incomplete information input’, financial e.g. ‘training cost’ and technical e.g. ‘lack of technical training’ that lead to negative impacts on team collaboration during the project. Although ICT and collaboration practices exist to a significant extent in construction projects, the current level of ICT and collaboration practices used in the industry does not support the adoption of collaborative BIM. Moreover, the use of inadequate data management solutions results in data errors, inconsistency, and poorly produced documents, which might have negative effects on the progress of construction projects. Further, there are more specific data-related issues including data inconstancy, compatibility, accessibility, security, and data storage problems. This highlights the importance of developing BIM governance solution to tackle most of the existing issues during team collaboration.

This study argues that cloud computing has still not been able to cope fully in dealing with issues related to construction data management. Data governance, for instance, is still an unresolved issue. For this reason, this study suggests that a governance platform should be developed on top of the cloud infrastructure to facilitate handling generated data during construction projects.

This study contributes to the body of knowledge by consolidating cloud-based BIM governance solution requirements that have been discussed in great details in section 4.2.5. This exploratory study critically reviews and further investigates the current collaboration and ICT practices landscape and gathers the requirements for developing a cloud-based BIM governance solution to address current industry collaboration problems on projects. The aim of this solution is to facilitate and to govern the collaboration processes of construction teams taking into account construction practitioners’ requirements. Further, a number of requirements for developing a BIM governance solution have been identified and classified into two main categories: (a) socio-organisational and legal requirements, and (b) technical requirements. It also has evaluates the intensity of importance of these requirements. In addition to contributing to the growing body of BIM adoption and collaboration knowledge, this paper shed light on the importance of BIM governance laying out the foundation for future research and development in this area. Future work will involve the implementation of a prototype with the aim of producing a Cloud-based BIM governance platform and testing the potential of such a platform in facilitating team collaboration during BIM-based projects.

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Table 1: Widely used collaborative solutions for BIM

BIM product	Specialization	Company	Website
Onuma system	BIM management and collaboration	Onuma Planning System	http://onuma.com/
Revit Server	Workspace sharing server for Autodesk BIM products	Autodesk	http://www.autodesk.com/
ProjectWise	Collaboration and content management	Bentley	http://www.bentley.com/
Graphisoft BIM Server	BIM team collaboration server	Graphisoft	https://www.graphisoft.com/
EDMmodelServer	IFC-based BIM server	Jotne	http://www.epmtech.jotne.com/
Autodesk BIM 360 Glue	BIM management and collaboration	Autodesk	http://www.autodesk.com/
Open-source BIM server	IFC-based BIM server	BIMserver. org	http:// http://bimserver.org

Table 2: Respondents' demographic information

Variable	Scale/Category	N	%
Age (yr)	18–21	2	1.7
	22–25	15	13.04
	26–30	20	17.39
	31–35	16	13.91
	36–40	17	14.68
	41–45	17	14.68
	46–50	15	13.04
	>51	13	11.30
Gender	Male	107	93.04
	Female	8	6.96
Work experience (yr)	<1	8	6.96
	1-5	18	15.65
	6-10	30	26.09
	11-15	15	13.04
	16-20	10	8.70
	>20	34	29.57
Qualification	College/Pre-university	12	10.62
	Vocational/Technical	27	23.89
	Undergraduate	44	38.9
	Postgraduate taught	34	30.1
	Postgraduate taught	4	3.5
Company age (yr)	1-10	19	17.9
	11-30	25	23.6
	>30	62	58.5
Occupation	Architect	29	32.6
	Building Surveyor	1	1.1
	BIM Manager	30	33.7
	Civil Engineer	6	6.7
	Client	1	1.1
	Client Advisor	2	2.2
	Contractor	5	5.6
	Electrical Engineer	1	1.1
	Facility Manager	1	1.1
	Non-Disciplinary	1	1.1
	Geographical & Land Surveyor	1	1.1
	Health & Safety Consultant	1	1.1
	Heating & Ventilation Designer	3	3.4
	Information Manager	6	6.7
	Interior Design	2	2.2
	IT Technician	5	5.6
	Mechanical Engineer	6	6.7
	Project Manager	8	9
	Public Health Engineer	1	1.1
	Quantity Surveyor	4	4.5
	Specialist Designer	3	3.4
	Structural Engineer	3	3.4
	Others	33	27.9

Table 3: Used procurement methods

Methods	Responses[a]					Mean	SD
	1	2	3	4	5		
Traditional	4	7	21	38	12	3.26	1.403
Design and build	3	4	17	48	12	3.38	1.398
Two stage tendering	5	7	24	36	6	3.01	1.426
Public private partnerships	10	14	21	22	9	2.75	1.495
Private finance initiative	12	10	25	19	6	2.50	1.532
Management contracting	10	18	19	24	2	2.40	1.466
Framework agreements	7	7	21	37	10	3.03	1.514
Prime contracting	14	12	15	19	6	2.28	1.640

[a] 1: Never; 2: Rarely; 3: Sometimes; 4: Often; 5: Always.

Table 4: Used communication tools between team members

Technologies/Tools	Responses[a]					Mean	SD
	1	2	3	4	5		
Landlines	3	5	13	34	24	3.90	1.033
Mobile phone/SMS	3	4	12	36	25	3.95	1.005
Email	1	2	0	23	55	4.59	0.738
Teleconference	8	15	19	27	9	3.18	1.181
Online voice/video meeting software	11	19	19	21	9	2.97	1.240
Face-to-face meeting	1	1	4	42	29	4.26	0.732

[a] 1: Never; 2: Rarely; 3: Sometimes; 4: Often; 5: Always.

Table 5: Respondents' methods for storing their data

Technologies/Tools	Responses[a]					Mean	SD
	1	2	3	4	5		
Paper	5	21	15	24	11	3.20	1.189
Optical media	6	22	24	16	5	2.89	1.061
Flash storage	7	14	26	22	7	3.11	1.102
Networked drive hosted by the company	2	5	7	20	44	4.27	1.040
Portable external hard drive	17	19	19	15	5	2.63	1.228
Cloud storage	8	16	29	18	7	3.00	1.105
On pc/laptop	13	18	17	15	13	2.96	1.350

[a] 1: Never; 2: Rarely; 3: Sometimes; 4: Often; 5: Always.

Table 6: Practitioners' methods for sharing and exchanging

Technologies/Tools	Responses[a]					Mean	SD
	1	2	3	4	5		
Paper	4	22	18	25	10	3.19	1.133
Optical media	12	21	21	17	7	2.82	1.203
Flash storage	8	22	24	20	3	2.84	1.052
Email	0	0	4	47	29	4.31	0.565
Networked drive by the company	9	4	15	27	23	3.65	1.277
Portable external hard drive	26	25	13	7	6	2.25	1.237
Cloud storage solution	9	15	17	24	15	3.26	1.280

[a]1: Never; 2: Rarely; 3: Sometimes; 4: Often; 5: Always.

Table 7: Most commonly used file format when sharing/ exchanging data

Item	Responses[a]					Mean	SD
	1	2	3	4	5		
Microsoft Word (e.g. .docx,.doc, etc.)	2	7	15	33	25	3.88	1.023
Microsoft Powerpoint (e.g. .pptx, .ppt, etc.)	6	17	18	24	15	3.31	1.217
Microsoft Excel (e.g. .xlsx, .xls, etc.)	2	4	16	35	22	3.90	0.955
Portable Document Format (.pdf)	0	0	3	32	43	4.51	0.575
Autodesk (.dwg)	0	6	14	37	22	3.95	0.875
AutoCAD (.dxf)	6	25	21	16	8	2.93	1.135
Bentley Microstation (.dgn)	34	21	7	10	5	2.10	1.283
Industry Foundation Classes(.ifc)	21	20	15	18	2	2.47	1.205
Comma-Separated Values(.csv)	28	24	14	9	2	2.13	1.116
Extensible Markup Language(.xml)	28	22	17	9	1	2.13	1.080
Green building XML schema(.gbxml)	34	24	12	4	1	1.85	0.968
Simple Text Format (.txt)	28	31	10	7	3	2.06	1.090
Image Format (e.g. .jpeg,.png, .gif, etc.)	1	11	24	30	12	3.53	0.963

[a]1: Never; 2: Rarely; 3: Sometimes; 4: Often; 5: Always.

Table 8: Practitioners' opinions about BIM data governance solution development

Technologies/Tools	Responses[a]					Mean	SD
	1	2	3	4	5		
New BIM governance solutions will change teams collaboration methods during projects	1	0	9	32	32	4.27	0.781
BIM governance solution will improve projects' quality and efficiency	2	2	8	36	25	4.10	0.900
BIM governance will speed up supply-chain collaboration during lifecycle	2	2	18	32	19	3.88	0.927
Developing BIM governance solution would tackle existing collaboration problems	1	8	25	27	13	3.58	0.950

[a]1: Strongly disagree; 2: Disagree; 3: Neither agrees nor disagree; 4: Agree; 5: Strongly agree.

Table 9: BIM governance solution requirements

Requirement	Responses[a]					Mean	SD
	1	2	3	4	5		
First Category: Socio-organizational and Legal requirements							
Improve the communication among disciplines	0	0	7	29	36	4.40	0.664
Development of collaboration protocols	0	0	9	27	36	4.38	0.700
Define clear roles, responsibilities for stakeholders across discipline through lifecycle	0	1	8	30	34	4.33	0.727
Awareness raising	0	0	13	38	22	4.12	0.686
Help and support	0	0	13	41	19	4.08	0.661
Standardized overall data management policy	0	1	13	38	19	4.06	0.715
Intensive training	0	1	16	36	20	4.03	0.745
Second Category: Technical Requirements							
A notification system to inform team members of updated data	0	1	8	35	27	4.24	0.706
Provide real-time mechanism for sharing/exchanging information	1	1	10	34	26	4.15	0.816
Central repository for data storage online	0	2	14	35	21	4.04	0.777
Sharing through a common BIM model	2	0	16	31	23	4.01	0.896
Use web for online viewing and printing models	0	4	16	35	16	3.89	0.820
Security checks for uploaded/ downloaded and transferred models	0	1	25	28	18	3.88	0.803
Secured log-in with access rights	0	3	23	30	16	3.83	0.828
User interface customization	0	4	25	29	13	3.72	0.831

[a]1: Strongly disagree; 2: Disagree; 3: Neither agrees nor disagree; 4: Agree; 5: Strongly agree.

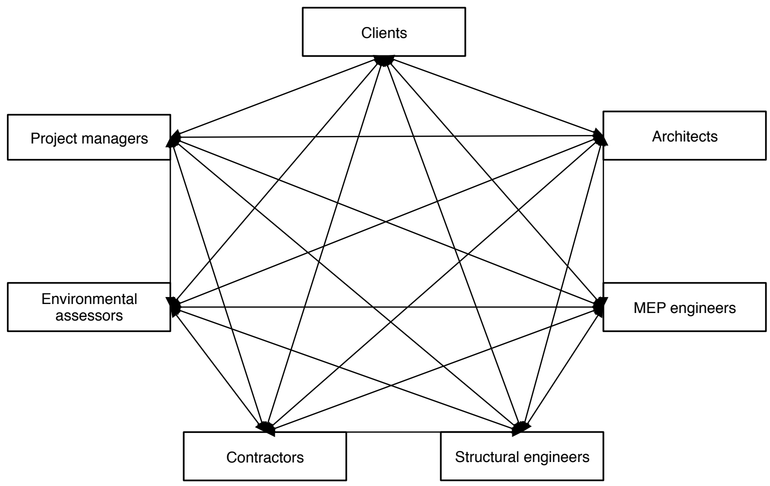

Figure 1: Data exchange pathways in a conventional construction project

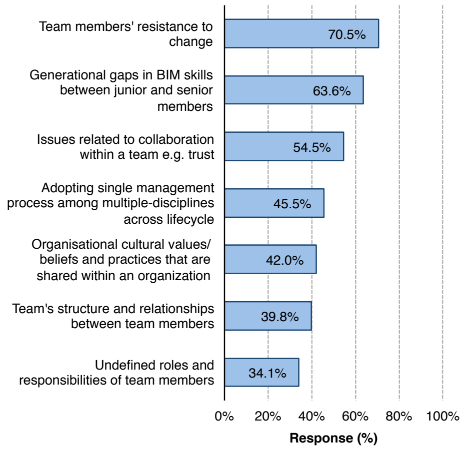

Figure 2: Socio-organisational barriers to BIM adoption

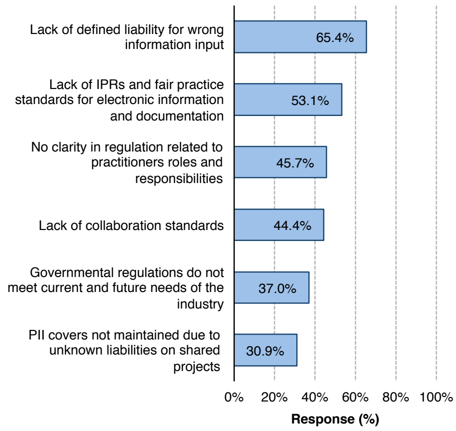

Figure 3: Legal barriers to BIM adoption

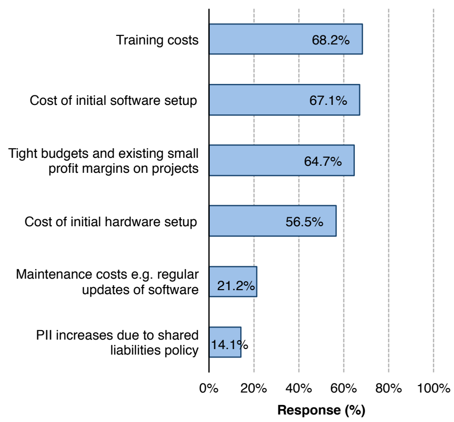

Figure 4: Financial barriers to BIM adoption

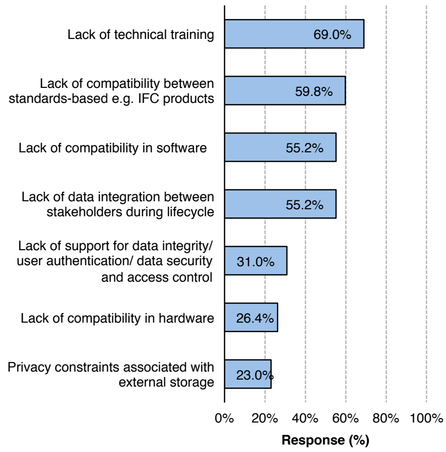

Figure 5: Technical barriers to BIM adoption

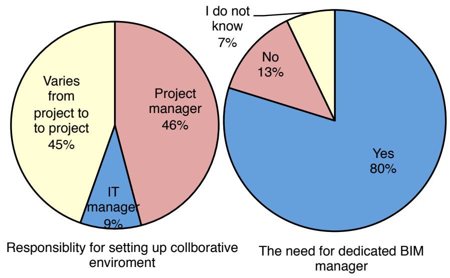

Figure 6: Responsibility of maintaining a project's collaborative environment

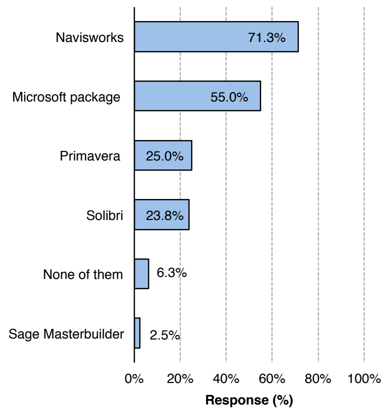

Figure 7: Used software for project management and planning

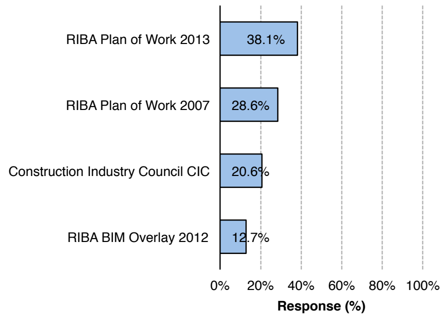

Figure 8: Used model for design and construction process

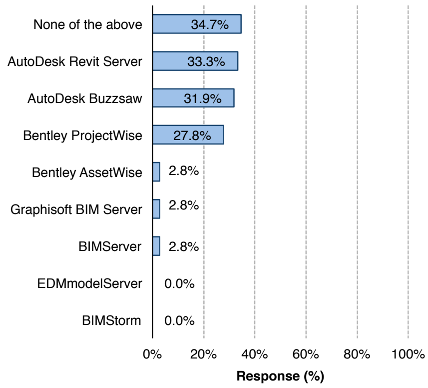

Figure 9: Level of using BIM collaboration servers

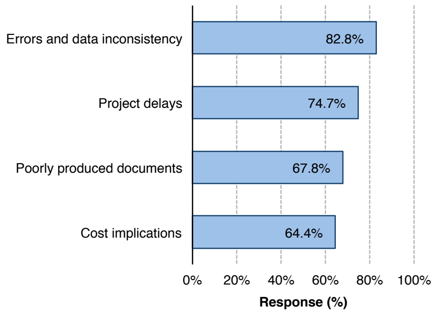

Figure 10: Impact of insufficient data management solutions

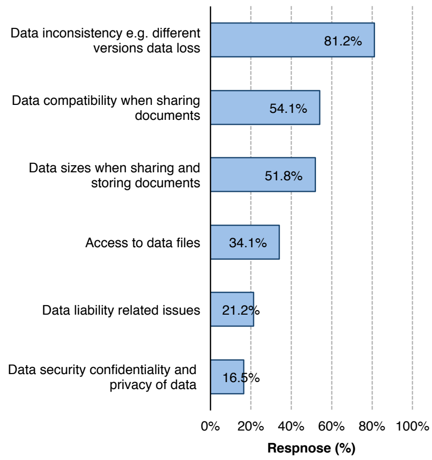

Figure 11: Most common data issues within construction projects

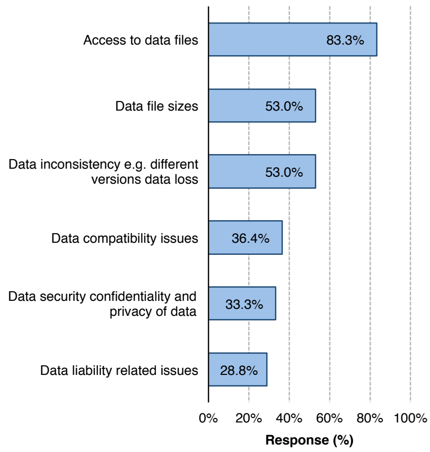

Figure 12: Role of cloud towards solving construction data-related issues

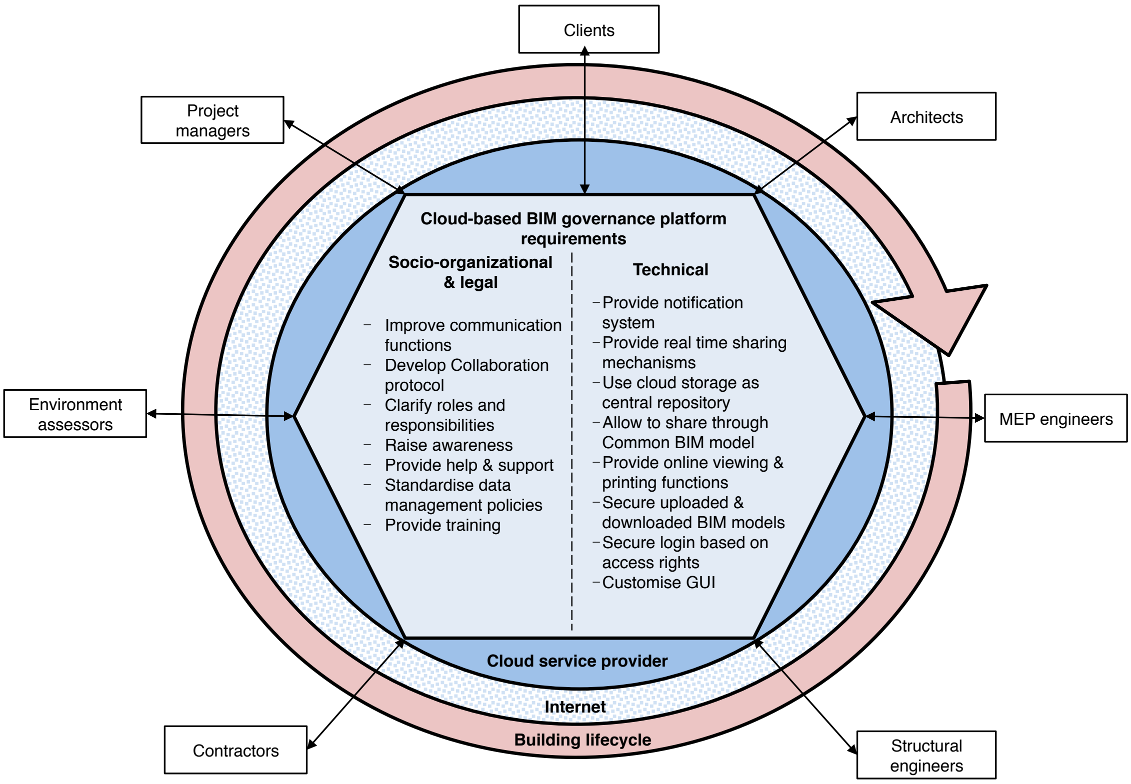

Figure 13: Proposed cloud-based BIM governance solution